Introduction: Kinematics in Multiple Dimensions

Unit: Kinematics (Motion) in Multiple Dimensions

Topics covered in this chapter:

In this chapter, you will study how things move and how the relevant quantities are related.

- *Projectile Motion* deals with an object that has two-dimensional motion—moving horizontally and also affected by gravity.
- *Angular Motion, Speed & Velocity* and *Angular Acceleration* deal with motion of objects that are rotating around a fixed center, using polar coördinates.
- *Centripetal Motion* deals with an object that is moving in a circle and therefore continuously accelerating toward the center.
- *Solving Linear & Rotational Motion Problems* deals with the relationships between linear and rotational kinematics problems and the types of problems that often appear on the AP® Physics exam.

Some of the challenging tasks include identifying quantities from their units, choosing the equation that relates the quantities of interest, and keeping track of positive and negative directions when working with vector quantities.

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This unit is part of *Unit 1: Kinematics* and *Unit 5: Torque and Rotational Dynamics* from the 2024 AP® Physics 1 Course and Exam Description.

Standards addressed in this chapter:

NGSS Standards/MA Curriculum Frameworks (2016):

Two-dimensional (projectile) motion and angular motion are not included in the MA Curriculum frameworks.

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AP® Physics 1 Learning Objectives/Essential Knowledge (2024):

1.5.B: Describe the motion of an object moving in two dimensions.

1.5.B.1: Motion in two dimensions can be analyzed using one-dimensional kinematic relationships if the motion is separated into components.

1.5.B.2: Projectile motion is a special case of two-dimensional motion that has zero acceleration in one dimension and constant, nonzero acceleration in the second dimension.

2.9.A: Describe the motion of an object traveling in a circular path.

2.9.A.1: Centripetal acceleration is the component of an object's acceleration directed toward the center of the object's circular path.

2.9.A.1.i: The magnitude of centripetal acceleration for an object moving in a circular path is the ratio of the object's tangential speed squared to the radius of the circular path.

2.9.A.1.ii: Centripetal acceleration is directed toward the center of an object's circular path.

2.9.A.2: Centripetal acceleration can result from a single force, more than one force, or components of forces exerted on an object in circular motion.

2.9.A.2.i: At the top of a vertical, circular loop, an object requires a minimum speed to maintain circular motion. At this point, and with this minimum speed, the gravitational force is the only force that causes the centripetal acceleration.

2.9.A.3: Tangential acceleration is the rate at which an object's speed changes and is directed tangent to the object's circular path.

2.9.A.4: The net acceleration of an object moving in a circle is the vector sum of the centripetal acceleration and tangential acceleration.

2.9.A.5: The revolution of an object traveling in a circular path at a constant speed (uniform circular motion) can be described using period and frequency.

2.9.A.5.i: The time to complete one full circular path, one full rotation, or a full cycle of oscillatory motion is defined as period, *T*.

2.9.A.5.ii: The rate at which an object is completing revolutions is defined as frequency, *f*.

2.9.A.5.iii: For an object traveling at a constant speed in a circular path, the period is given by the derived equation: $T = \frac{2\pi r}{v}$.

5.1.A: Describe the rotation of a system with respect to time using angular displacement, angular velocity, and angular acceleration.

5.1.A.1: Angular displacement is the measurement of the angle, in radians, through which a point on a rigid system rotates about a specified axis.

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5.1.A.1.i: A rigid system is one that holds its shape but in which different points on the system move in different directions during rotation. A rigid system cannot be modeled as an object.

5.1.A.1.ii: One direction of angular displacement about an axis of rotation—clockwise or counterclockwise—is typically indicated as mathematically positive, with the other direction becoming mathematically negative.

5.1.A.1.iii: If the rotation of a system about an axis may be well described using the motion of the system's center of mass, the system may be treated as a single object. For example, the rotation of Earth about its axis may be considered negligible when considering the revolution of Earth about the center of mass of the Earth–Sun system.

5.1.A.2: Average angular velocity is the average rate at which angular position changes with respect to time.

5.1.A.3: Average angular acceleration is the average rate at which the angular velocity changes with respect to time.

5.1.A.4: Angular displacement, angular velocity, and angular acceleration around one axis are analogous to linear displacement, velocity, and acceleration in one dimension and demonstrate the same mathematical relationships.

5.1.A.4.i: For constant angular acceleration, the mathematical relationships between angular displacement, angular velocity, and angular acceleration can be described with rotational versions of the kinematic equations.

5.1.A.4.ii: As with translational motion, graphs of angular displacement, angular velocity, and angular acceleration as functions of time can be used to find the relationships between those quantities.

5.2.A: Describe the linear motion of a point on a rotating rigid system that corresponds to the rotational motion of that point, and vice versa.

5.2.A.1: For a point at a distance *r* from a fixed axis of rotation, the linear distance *s* traveled by the point as the system rotates through an angle $\Delta\theta$ is given by the equation $\Delta s = r\Delta\theta$.

5.2.A.2: Derived relationships of linear velocity and of the tangential component of acceleration to their respective angular quantities are given by the following equations: $\Delta s = r\Delta\theta$, $v_T = r\omega$, and $a_T = r\alpha$.

5.2.A.3: For a rigid system, all points within that system have the same angular velocity and angular acceleration.

Skills learned & applied in this chapter:

- Choosing from a set of equations based on the quantities present.
- Working with vector quantities.
- Keeping track of things happening in two directions at once.

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